APPENDIX D   BMP DESIGN EXAMPLES

Appendix D BMP Sizing Worksheets

Contents

Appendix D BMP Sizing Worksheets 1
Bioretention Worksheet 2
Bioretention Design Example 4
Vegetated Swale Filter Worksheet 6
Vegetated Swale Filter Design Example 9
Vegetated Filter Strip Worksheet 13
Vegetated Filter Strip Design Example 15
Sand Filter Worksheet 17
Sand Filter Design Example 19
Infiltration BMP Worksheet 21
Infiltration BMP Design Example 23
Permeable Pavement Worksheet 26
Permeable Pavement Design Example 28
Constructed Treatment Wetland Worksheet 31
Constructed Treatment Wetland Design Example 35
Wet Retention Basin Worksheet 39
Wet Retention Basin Design Example 43
Dry Extended Detention Basin Worksheet 47
Dry Extended Detention Basin Design Example 50

Bioretention Worksheet

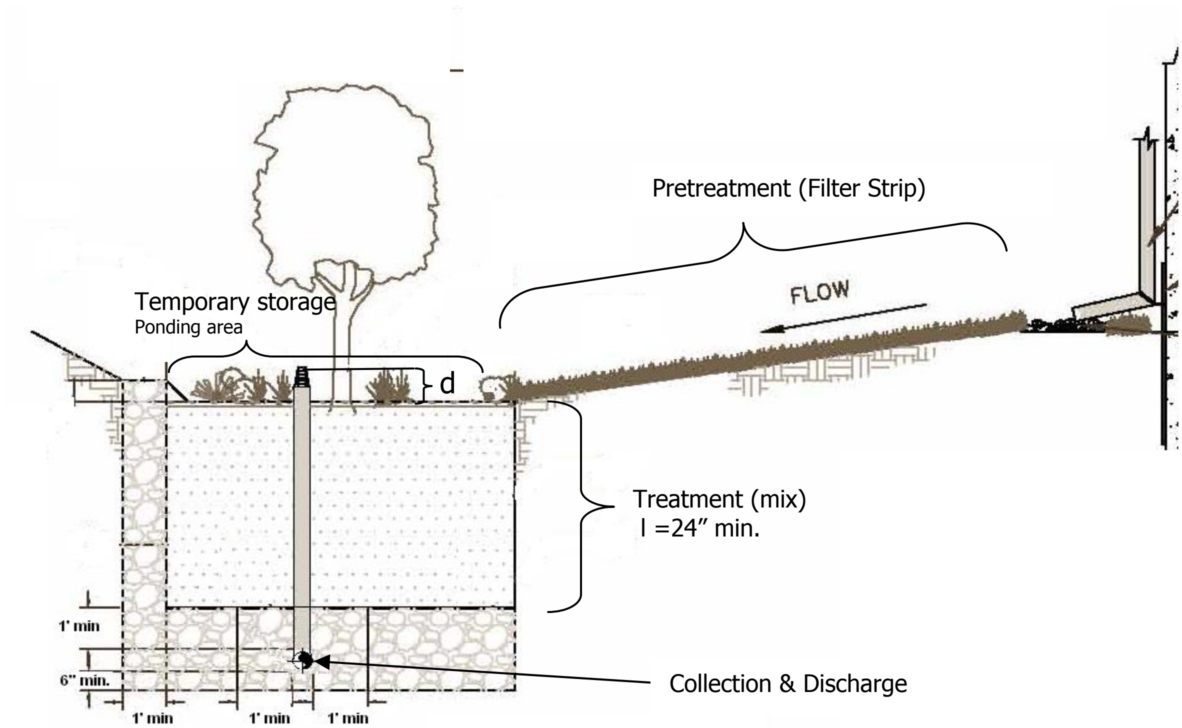

Figure D-1: Bioretention Area Cross-Section

Refer to Figure D-1 and Figure 6-2 for the description of the geometric variables.

Step 1: Determine design volume reduction, $V_{reduction}$	
1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25}, calculated using SBUH method, Appendix C	V_{25} = __________ ft^3
1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one\text{-}inch}$, calculated using SBUH method, Appendix C	$V_{one\text{-}inch}$ = __________ ft^3
1-3. Determine design volume reduction which is the larger of V_{25} and $V_{one\text{-}inch}$ and is the volume to be retained on-site	$V_{reduction}$ = __________ ft^3
Step 2: Determine storm water quality design volume, V_{wq}	
2-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} = __________ ft^3
Step 3: Determine design volume, V_{design} (for sizing)	
3-1. If underdrain system is used, $V_{design} = V_{wq}$ If there is no underdrain system, V_{design} = the larger of $V_{reduction}$ and V_{wq}	V_{design} = __________ ft^3

Step 4: Pretreatment	
4-1. If pretreatment is required please go the vegetated filter strip worksheet, Appendix C	
Step 5: Calculate bioretention area	
5-1. Enter thickness of planting mix (min. 24"), l	l = __________ in
5-2. Enter storage depth (18" max.) above the filter, d	d = __________ in
5-3. Enter infiltration rate (0.375"/hr), k_{design} (Note: infiltration rate of planting media, if no underdrain infiltration rate of native subsoil or fill). If no underdrains, see Step 4 of the Infiltration BMP Worksheet, Appendix D to calculate k_{design}).	k_{design} = __________ in/hr
5-4. Enter drawdown time, t	t = __________ hr
5-5. Calculate bioretention area, $A_{sf} = (V_{design} \cdot l)/[(t \cdot k_{design}/12) \cdot (l+d)]$	A_{sf} = __________ ft^2
Step 6: Calculate underdrain system flow rate (if an underdrain is provided)	
6-1. Calculate filtered flow rate to be conveyed by the longitudinal drain pipe, $Q_f = k_{design} \cdot A_{sf}/43200$ (Note: for this example, step 6-1 is equivalent to step 5-1 of the Sand Filter Worksheet, Appendix D).	Q_f = __________ cfs
6-2. Please follow steps 5-2 through 5-7 of the Sand Filter Worksheet, Appendix D to calculate the underdrain system capacity.	
Step 7: Provide Conveyance Capacity for Flows Higher than Q_{wq}	
7-1. An emergency overflow must be provided if the bioretention area is placed online or in the event the surface area becomes clogged.	

Bioretention Design Example

Bioretention areas have several components that allow the pretreatment, spreading, filtration, collection and discharge of the incoming flows.

Step 1: Determine Storm Water Quality Design Volume Reduction, $V_{reduction}$

Step 1: Determine design volume reduction, $V_{reduction}$		
1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25}, calculated using SBUH method, Appendix C	V_{25} = 20	ft^3
1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one\text{-}inch}$, calculated using SBUH method, Appendix C	$V_{one\text{-}inch}$ = 25,700	ft^3
1-3. Determine design volume reduction which is the larger of V_{25} and $V_{one\text{-}inch}$ and is the volume to be retained on-site	$V_{reduction}$ = 25,700	ft^3

Step 2: Determine Storm Water Quality Design Volume, V_{wq}

Step 2: Determine storm water quality design volume, V_{wq}		
2-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} = 25,700	ft^3

Step 3: Determine Design Volume, V_{design}

Step 3: Determine design volume, V_{design} (for sizing)		
3-1. If underdrain system is used, $V_{design} = V_{wq}$ If there is no underdrain system, V_{design} = the larger of $V_{reduction}$ and V_{wq}	V_{design} = 25,700	ft^3

Step 4: Pretreatment

Step 4: Pretreatment
4-1. If pretreatment is required please go the vegetated filter strip worksheet, Appendix C

The bioretention areas that collect runoff from residential roofs, sidewalks, driveways, or other "cleaner" surfaces do not require pretreatment. If the runoff originates from locations other than "clean" surfaces, then pretreatment is required. Please refer to Vegetated Filter Strip Worksheet (Appendix D) for detailed calculations.

Step 5: Determine bioretention area footprint area

A bioretention area is designed with two components: (1) temporary storage reservoir to store runoff, and (2) a plant mix filter bed (planting soil mixed with sand content = 70%) through which the stored runoff must percolate to obtain treatment.

The simple sizing method does not route flows through the filter which would allow a more accurate sizing of the facility. The size of the filter is determined based on the simple assumption that inflow is immediately discharged through the filter at a rate not less than 0.375 in/hr which is equivalent to drawing down the maximum 18" storage depth over 48 hours (0.375 in/hr = 18 in/48 hr).

Step 5: Calculate bioretention area			
5-1. Enter thickness of planting mix (min. 24"), l	l =	24	in
5-2. Enter storage depth (18" max.) above the filter, d	d =	18	in
5-3. Enter infiltration rate (0.375"/hr), k_{design} (Note: infiltration rate of planting media, if no underdrain infiltration rate of native subsoil or fill). If no underdrains, see Step 4 of the Infiltration BMP Worksheet, Appendix D to calculate k_{design}).	k_{design} =	0.375	in/hr
5-4. Enter drawdown time, t	t =	48	hr
5-5. Calculate bioretention area, $A_{sf} = (V_{design} \cdot l)/[(t \cdot k_{design}/12) \cdot (l+d)]$	A_{sf} =	9,790	ft^2

Step 6: Calculate Underdrain System

If an underdrain is required, please see the Sand Filter underdrain calculation, Appendix D. All underdrain pipes must be 6 inches or greater to facilitate cleaning.

Step 6: Calculate underdrain system flow rate (if an underdrain is provided)			
6-1. Calculate filtered flow rate to be conveyed by the longitudinal drain pipe, $Q_f = k \cdot A_{sf}/43200$ (Note: for this example, step 6-1 is equivalent to step 5-1 of the Sand Filter Worksheet, Appendix D).	Q_f =	0.1487	cfs
6-2. Please follow steps 5-2 through 5-7 of the Sand Filter Worksheet, Appendix D to calculate the underdrain system capacity.			

Step 7: Provide Conveyance Capacity for Flows Higher than Q_{WQ}

Provide conveyance capacity for flows higher than Q_{wq}, water quality design flow rate, to bypass the bioretention area. An emergency overflow must also be provided in the event that the surface area becomes clogged or the bioretention area is placed online.

Vegetated Swale Filter Worksheet

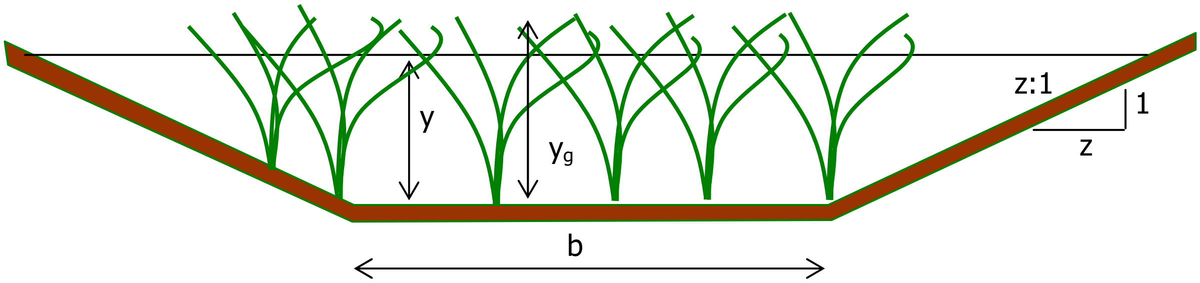

Figure D-2: Vegetated swale filter cross-section

Refer to Figure D-2, Figure 6-5, and Figure D-2 for a diagrammatic description of the geometric variables.

Step 1: Determine design volume reduction, $V_{reduction}$ (if applicable)	
1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25}, calculated using SBUH method, Appendix C	V_{25} = __________ ft^3
1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one\text{-}inch}$, calculated using SBUH method, Appendix C	$V_{one\text{-}inch}$ = __________ ft^3
1-3. Determine the design volume reduction, $V_{reduction}$, which is the larger of V_{25} and $V_{one\text{-}inch}$ and is the volume to be retained on-site **Note**: Volume reduction credit is only provided for vegetated swale filters that include a gravel drainage layer to encourage infiltration.	$V_{reduction}$ = __________ ft^3

Step 2: Determine storm water quality design flow rate, Q_{wq}	
2-1. Enter drainage area, A	A = __________ acres
2-2. Enter impervious fraction, Imp	Imp = __________
2-3. Calculate runoff coefficient, C = (0.9•Imp + 0.05)	C = __________
2-4. Calculate the water quality design flow rate, Q_{wq}, based on a constant rainfall intensity of 0.25 in/hr, Appendix C	Q_{wq} = __________ cfs

Step 3: Determine design volume for sizing gravel drainage layer, if applicable	
3-1. $V_{design} = V_{reduction}$	V_{design} = __________ ft^3
3-2. Please follow Steps 3 through 5 of the Permeable Pavement Worksheet, Appendix D to calculate the size of the gravel drainage layer	

Step 4: Calculate flow depth, d, and swale bottom width, b		
4-1. Enter Manning's roughness coefficient for shallow flow conditions (0.2 typical), n	n = _________	
4-2. Enter expected vegetation height, y_v	y_v = _________	in
4-3. Calculate design flow depth (0.33 ft max), $d = y_v/18$	d = _________	ft
4-4. Enter longitudinal slope (along direction of flow), s	s = _________	ft/ft
4-5. Enter side slope length per unit height (e.g. 3 if side slope are 3H :1V), Z	Z = _________	
4-6. Calculate bottom width of swale assuming a trapezoidal channel shape, $b = Q_{wq}n_{wq}/1.49y^{1.67}s^{0.5}$	b = _________	ft
4-7. Calculate $AR^{2/3}$, using $Q_{wq}n/1.49s^{0.5}$ (Equation 6-5)	$AR^{2/3}$ = _________	
4-8. Calculate the wetted area, A	A = _________	ft^2
4-9. Calculate the wetted perimeter, P	P = _________	ft
4-10. Calculate the hydraulic radius, R	R = _________	ft
4-11. Re-calculate $AR^{2/3}$, using the A and R calculated in steps 4-8 and 4-10. Change b until the $AR^{2/3}$ calculated in this step is equal to $AR^{2/3}$ calculated in 4-7.	$AR^{2/3}$ = _________	
4-12. If b is between 2 and 10 feet, go to Step 5		
4-13. If b < 2 ft, set b = 2 ft and go to Step 4-4 and decrease swale slope (0.015 ft/ft max.). If slope cannot be changed due to site constraints, go to Step 4-14.		
4-14. If b < 2 ft and slope is maximized, set b= 2 ft and go to Step 4-2 and decrease vegetation height		
4-15. If b is greater than 10 ft, one of the following design adjustments must be made: 1) increase the longitudinal slope to a maximum of 0.06 ft/ft, and repeat steps 4-7 to 4-11 above. 2) include a flow splitter longitudinally along the swale bottom (Figure 6-6 and Appendix F) at least three-quarters of the swale length (beginning at the inlet)		
Step 5: Determine design flow velocity		
5-1. Calculate design flow velocity, $v_{wq} = Q_{wq}/A$	v_{wq} = _________	ft/s
5-2. If the design flow velocity is higher than 1ft/s go to Step 4-4 and decrease the slope, if possible		
Step 6: Calculate swale length		
6-1. Enter target residence time (10 minutes minimum), t_{HR}	t_{HR} = _________	min
6-1. Calculate swale length, $L = v_{wq} \cdot 60 \cdot t_{HR}$	L = _________	ft
6-2. If L is too long for the site, proceed to step 5 to adjust the swale layout		

Step 7: Adjust swale layout to fit within site constraints		
7-1. Choose a reduced swale length, L_f	L_f = ________	ft
7-2. Recalculate flow velocity, $v_{wq} = L_f / (t_{HR} \cdot 60)$	v_{wq} = ________	ft/s
7-3. Recalculate cross-sectional area, $A_{wq} = Q_{wq} / v_{wq}$	A_{wq} = ________	ft^2
7-4. Calculate an increased bottom width, $b_f = (A_{wq} - Zy^2) / y$	b_f = ________	ft
7-5. Recalculate longitudinal slope assuming a rectangular channel shape, $s_f = [Q_{wq} n_{wq/(}1.49 A_{wq} y^{0.67})]^2$	s_f = ________	ft/ft
7-6. If s_f is between 1.5% and 6%, the swale design is acceptable for water quality, proceed to Step 6 7-7. If s_f is between 1% and 1.5%, the swale design is acceptable for water quality with underdrains (see design requirements). Proceed to Step 6. 7-8. If s_f is <1%, the swale design is unacceptable. Consider subdividing drainage area and repeat all above steps, or choose a different BMP for the site.		
Step 8: Provide conveyance capacity for flows higher than Q_{wq}		
8-1. If the swale already includes a high-flow bypass to convey flows higher than the water quality design flow rate, skip this step and verify that all parameters meet design requirements to complete sizing.		
8-2. If swale does not include a high-flow bypass, check the swale size for the peak discharge rate that will be conveyed in the swale. If online, the peak discharge rate is the 100-yr, 24-hr design storm calculated using the SBUH method (See Appendix C). Calculate the peak discharge velocity, $v_{peak} = Q_{peak}/A_{swale,}$ where Q_{peak} = the peak discharge rate (cfs) and A_{swale} = the cross-sectional area of the swale including freeboard (ft^2)	V_{peak} = ________	ft/s
8-3. If V_{peak} > 3.0 feet per second, return to Step 2 and increase the bottom width or flatten the longitudinal slope as necessary to reduce the peak discharge flow velocity to 3.0 feet per second or less. If the longitudinal slope is flattened, the swale bottom width must be recalculated (Step 2) and must meet all design criteria.		

Vegetated Swale Filter Design Example

Step 1: Determine Storm Water Quality Design Volume Reduction, $V_{reduction}$

Step 1: Determine design volume reduction, $V_{reduction}$ (if applicable)		
1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25}, calculated using SBUH method, Appendix C	V_{25} = 20	ft^3
1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one\text{-}inch}$, calculated using SBUH method, Appendix C	$V_{one\text{-}inch}$ = 25,700	ft^3
1-3. Determine the design volume reduction, $V_{reduction}$, which is the larger of V_{25} and $V_{one\text{-}inch}$ and is the volume to be retained on-site,	$V_{reduction}$ = 25,700	ft^3
Note: Volume reduction credit is only provided for vegetated swale filters that include a gravel drainage layer to encourage infiltration.		

Step 2: Determine Storm Water Quality Design Flow

For this design example, a 10-acre residential development with a 60% total impervious area is considered. Flow-based sizing as described in Appendix C is assumed. Therefore, the design intensity is 0.25 in/hr.

Step 2: Determine storm water quality design flow rate, Q_{wq}		
2-1. Enter drainage area, A	A = 10	acres
2-2. Enter impervious fraction, Imp	Imp = 0.60	
2-3. Calculate runoff coefficient, C = (0.9•Imp + 0.05)	C = 0.59	
2-4. Calculate the water quality design flow rate, Q_{wq}, based on a constant rainfall intensity of 0.25 in/hr, Appendix C	Q_{wq} = 1.48	cfs

Step 3: Determine design volume for sizing gravel drainage layer

Step 3: Determine design volume for sizing gravel drainage layer		
3-1. $V_{design} = V_{reduction}$	V_{design} = 25,700	ft^3
3-2. Please follow Steps 3 through 5 of the Permeable Pavement Worksheet, Appendix D to calculate the gravel drainage layer		

Step 4: Calculate flow depth, d, and swale bottom width

The swale bottom width is calculated based on Manning's equation. The grass height in the swale will be maintained at 6-inches. Therefore, the design flow depth is assumed to be 2/3 of 4 inches, or 4 inches (0.33 ft). The default Manning's roughness coefficient is assumed appropriate for expected vegetation density and design depth.

Step 4: Calculate flow depth, d, and swale bottom width, b			
4-1. Enter Manning's roughness coefficient for shallow flow conditions (0.2 typical), n	n =	0.2	
4-2. Enter expected vegetation height, y_v	y_v =	6	in
4-3. Calculate design flow depth (0.33 ft max), d = $y_v/18$	d =	0.33	ft
4-4. Enter longitudinal slope (along direction of flow), s	s =	0.04	ft/ft
4-5. Enter side slope length per unit height (e.g. 3 if side slope are 3H :1V), Z	Z =	3	
4-6. Calculate bottom width of swale assuming a trapezoidal channel shape, b = $Q_{wq}n_{wq}/1.49y^{1.67}s^{0.5}$	b =	9.0	ft
4-7. Calculate $AR^{2/3}$, using $Q_{wq}n\ /1.49s^{0.5}$ (Equation 6-5)	$AR^{2/3}$ =	1.0	
4-8. Calculate the wetted area, A	A =	3.3	ft^2
4-9. Calculate the wetted perimeter, P	P =	11.1	ft
4-10. Calculate the hydraulic radius, R	R =	0.3	ft
4-11. Re-calculate $AR^{2/3}$, using the A and R calculated in steps 4-8 and 4-10. Change b until the $AR^{2/3}$ calculated in this step is equal to $AR^{2/3}$ calculated in 4-7.	$AR^{2/3}$ =	1.0	
4-12. If b is between 2 and 10 feet, go to Step 5			
4-13. If b < 2 ft, set b = 2 ft and go to Step 4-4 and decrease swale slope (0.015 ft/ft max.). If slope cannot be changed due to site constraints, go to Step 4-14.			
4-14. If b < 2 ft and slope is maximized, set b= 2 ft and go to Step 4-2 and decrease vegetation height			
4-15. If b is greater than 10 ft, one of the following design adjustments must be made: 1) increase the longitudinal slope to a maximum of 0.06 ft/ft, and repeat steps 4- to 4-11 above. 2) include a flow splitter longitudinally along the swale bottom (Figure 6-6 and Appendix F) at least three-quarters of the swale length (beginning at the inlet)			

Step 5: Determine Design Flow Velocity

Step 5: Determine design flow velocity			
5-1. Calculate design flow velocity, $v_{wq} = Q_{wq}/A$	v_{wq} =	0.4	ft/s
5-2. If the design flow velocity is higher than 1 ft/s go to Step 4-4 and decrease the slope, if possible			

Step 6: Calculate Swale Length

Using the design flow velocity and a minimum residence time of 10 minutes, the length of the swale is calculated as follows. The swale length must be a minimum of 100 ft.

Step 6: Calculate swale length			
6-1. Enter target residence time (10 minutes minimum), t_{HR}	t_{HR} =	10	min
6-1. Calculate swale length, $L = v_{wq} \bullet 60 \bullet t_{HR}$	L =	266	ft
6-2. If L is too long for the site, proceed to step 5 to adjust the swale layout			

Site constraints only allow a swale length of 200 feet. Therefore, proceed to Step 5 to adjust the swale length.

Step 7: Adjust Swale Layout to Fit Within Site Constraints

To adjust swale length to 200 feet, the bottom width needs to be increased (up to a maximum of 16 ft).

Step 7: Adjust swale layout to fit within site constraints			
7-1. Choose a reduced swale length, L_f	L_f =	250	ft
7-2. Recalculate flow velocity, $v_{wq} = L_f / (t_{HR} \bullet 60)$	v_{wq} =	0.42	ft/s
7-3. Recalculate cross-sectional area, $A_{wq} = Q_{wq} / v_{wq}$	A_{wq} =	3.5	ft^2
7-4. Calculate an increased bottom width, $b_f = (A_{wq} - Zy^2) / y$	b_f =	9.6	ft
7-5. Recalculate longitudinal slope assuming a rectangular channel shape, $s_f = [Q_{wq} n_{wq/(} 1.49\ A_{wq}\ y^{0.67})]^2$	s_f =	0.016	ft/ft
7-6. If s_f is between 1.5% and 6%, the swale design is acceptable for water quality, proceed to Step 6			
7-7. If s_f is between 1% and 1.5%, the swale design is acceptable for water quality with underdrains (see design requirements). Proceed to Step 6.			
7-8. If s_f is <1%, the swale design is unacceptable. Consider subdividing drainage area and repeat all above steps, or choose a different BMP for the site.			

Since width > 10 feet, the swale design is acceptable if a swale divider is included.

Step 8: Provide Conveyance Capacity for Flows Higher than Q_{wq}

The swale will be offline such that all flows greater than Q_{wq} will be bypassed.

Vegetated Filter Strip Worksheet

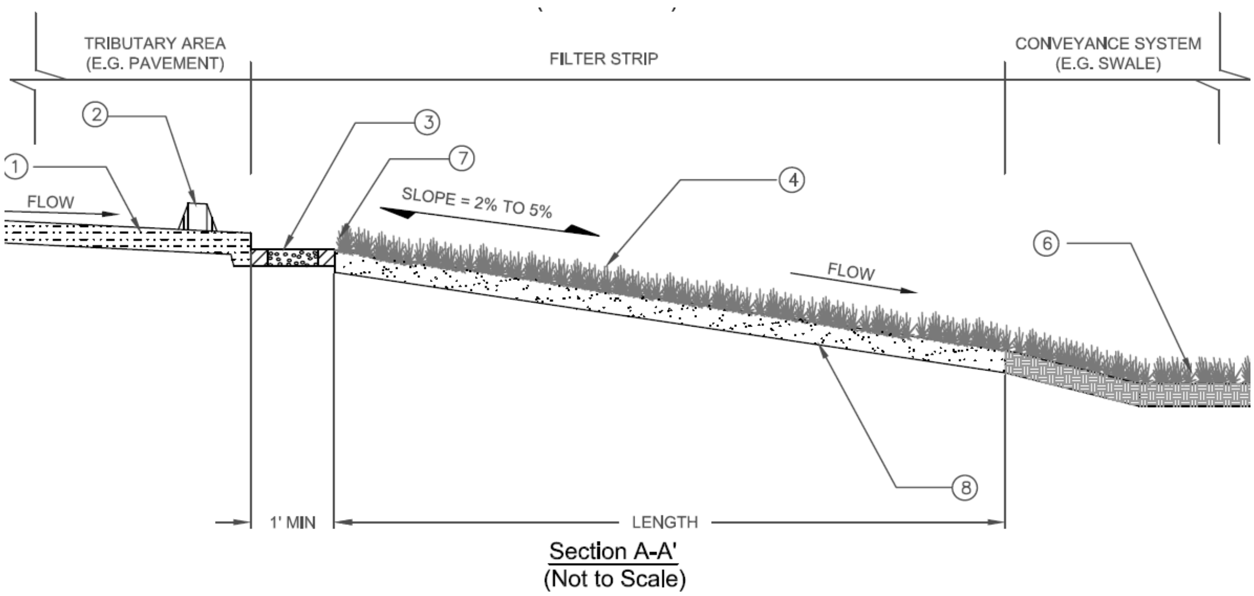

Figure D-3: Vegetated filter strip cross-section

Refer to Figure D-3 and Figure 6-8 for the description of the geometric variables.

Step 1: Calculate the design flow		
1-1. Enter drainage area, A	A = __________	acres
1-2. Enter impervious fraction, Imp	Imp = __________	
1-3. Calculate runoff coefficient, C = (0.9•Imp + 0.05)	C = __________	
1-4. Calculate the water quality design flow rate, Q_{wq}, based on a constant rainfall intensity of 0.25 in/hr, Appendix C	Q_{wq} = __________	cfs
Step 2: Calculate the design flow depth		
2-1. Enter strip filter slope (in direction of flow), s	s = __________	
2-2. Enter Manning roughness coefficient (0.25-.3), n_{wq}	n_{wq} = __________	
2-3. Enter width of impervious surface contributing area , W	W = __________	ft
2-4. Calculate average depth of water using Manning eq, $d_f = 12[Q_{wq}n_{wq}/1.49Ws^{0.5}]^{0.6}$	d_f = __________	in
2-5. If d_f > 1" , go Step 2-1 and decrease the slope		
2-6. If the slope cannot be changed due to construction constraints, go Step 2-3 and increase the width perpendicular to flow		
2-7. If d_f > 1" and neither the slope nor the width can be changed adequately, choose an alternate BMP for the site		

Step 3: Calculate the design velocity		
3-1. Calculate design flow velocity, $V_{wq} = Q_{wq}/d_fW$	V_{wq} = ___________	ft/s
3-2. If the design flow velocity is higher than 1ft/s go to step 2-1 and decrease the slope		
Step 4: Calculate the length of the filter strip		
4-1. Enter residence time (10 minutes, min.), t	t = ___________	min
4-2. Calculate length of the filter strip, $L = 60tV_{wq}$	L = ___________	ft
4-3. If L < 4 ft (pre-treatment) or less L< 15 ft (treatment), go to step 2-1 and increase the slope		

Vegetated Filter Strip Design Example

Step 1: Calculate the Design Flow

For this design example, a 10-acre residential development with a 60% total impervious area is considered. Flow-based sizing, as described in Appendix C, is assumed. Therefore, the design rainfall intensity is assumed to be 0.25 in/hr.

Step 1: Calculate the design flow			
1-1. Enter drainage area, A	A =	10	acres
1-2. Enter impervious fraction, Imp	Imp =	0.60	
1-3. Calculate runoff coefficient, C = (0.9•Imp + 0.05)	C =	0.59	
1-4. Calculate the water quality design flow rate, Q_{wq}, based on a constant rainfall intensity of 0.25 in/hr, Appendix C	Q_{wq} =	1.48	cfs

Step 2: Calculate the Design Flow Depth

Based on the site constraints we choose the width of the filter strip 150 ft and the filter strip longitudinal slope as 3%. The design water depth should not exceed 1 inch.

Step 2: Calculate the design flow depth			
2-1. Enter strip filter slope (in direction of flow), s	s =	0.03	
2-2. Enter Manning roughness coefficient (0.25-.3), n_{wq}	n_{wq} =	0.27	
2-3. Enter width of impervious surface contributing area , W	W =	150	ft
2-4. Calculate average depth of water using Manning eq, $d_f = 12[Q_{wq}n_{wq}/1.49Ws^{0.5}]^{0.6}$	d_f =	0.77	in
2-5. If d_f > 1" , go Step 2-1 and decrease the slope			
2-6. If the slope cannot be changed due to construction constraints, go Step 2-3 and increase the width perpendicular to flow			
2-7. If d_f > 1" and neither the slope nor the width can be changed adequately, choose an alternate BMP for the site			

Step 3: Calculate the Design Velocity

The designed flow velocity should not exceed 1 foot/second across the filter strip.

Step 3: Calculate the design velocity			
3-1. Calculate design flow velocity, $V_{wq} = Q_{wq}/d_fW$	V_{wq} =	0.1532	ft/s
3-2. If the design flow velocity is higher than 1ft/s go to step 2-1 and decrease the slope			

Step 4: Calculate the Length of the Filter Strip

The filter strip should be at least 4 feet long (in the direction of flow) and accommodate a minimum residence time of 10 minutes to provide adequate water quality treatment.

Step 4: Calculate the length of the filter strip			
4-1. Enter residence time (10 minutes, min.), t	t =	10	min
4-2. Calculate length of the filter strip, $L = 60tV_{wq}$	L =	91.9	ft
4-3. If L < 4 ft (pre-treatment) or less L< 15 ft (treatment), go to step 2-1 and increase the slope			

Sand Filter Worksheet

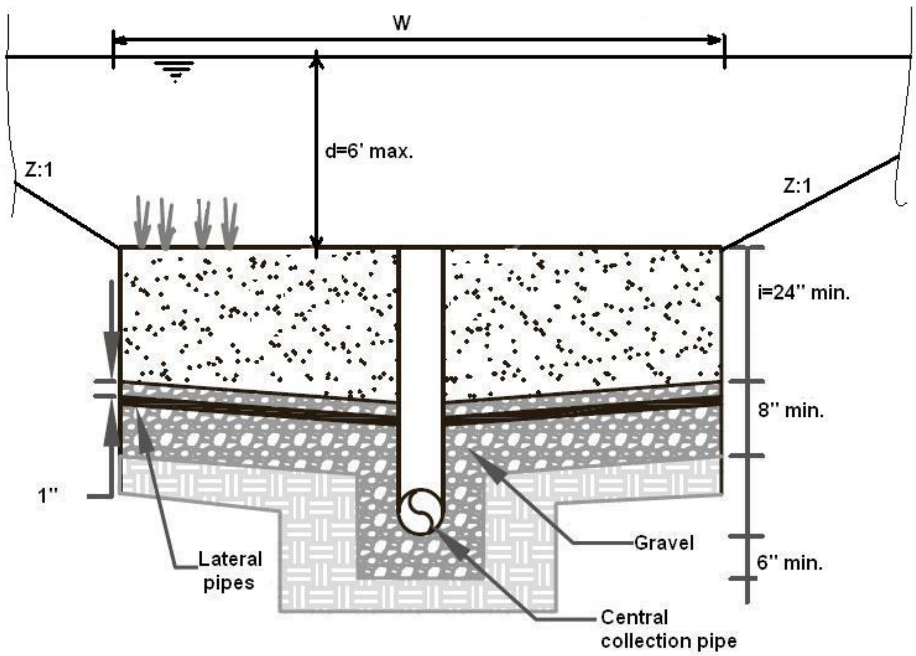

Figure D-4: Sand filter cross-section

Refer to Figure D-4 and Figure 6-10 for a diagrammatic description of the geometric variables.

Step 1: Determine storm water quality design volume, V_{wq}			
1-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} =	25,700	ft^3
Step 2: Calculate sand filter area			
2-1. Enter thickness of sand filter (min. 24" or 2'), l	l =	2	ft
2-2. Enter maximum storage depth (6 feet) above the filter, d	d =	6	ft
2-3. Enter routing adjustment factor, R	R =	0.7	
2-4. Calculate average depth of water above the filter, h = d/2	h =	3	ft
2-5. Enter hydraulic conductivity (1"/hr), K_i	K_i =	1	in/hr
2-6. Calculate hydraulic conductivity (ft/day), $K_{day} = 2K_i$	K_{day} =	2	ft/day
2-7. Calculate hydraulic gradient, i = (h+l)/l	i =	2.5	ft/ft
2-8. Enter drawdown time, t	t =	2	day
2-9. Calculate sand filter area, $A_{sf} = (V_{wq}Rl)/(K_{day}t(h+l))$	A_{sf} =	1,799	ft^2

Step 3: Determine filter dimensions			
3-1. Sand filter area, A_{sf}	A_{sf} =	1,799	ft^2
3-2. Enter geometric configuration, L_R:W ratio (2:1), L_R	L_R =	2	
3-3. Calculate the width of the sand filter, W	W =	30.0	ft
3-4. Calculate the length of the sand filter, L	L =	60.0	ft
3-5. Calculate rate of filtration, $r_{wq} = K_{day}i$	r_{wq} =	5.0	$ft/d/ft^2$

Step 4: Calculate storage volume			
4-1. Enter interior side slopes, 3H:1V (max), Z	Z =	3	
4-2. Calculate top length, $L_t = L + 2Zd$	L_t =	96.0	ft
4-3. Calculate top width, $W_t = W + 2Zd$	W_t =	66.0	ft
4-4. Calculate filter storage volume, $V_s = 1/3 \cdot d(A_{sf}+A_t+(A_{sf}A_t)^{0.5})$ where $A_t = L_t \cdot W_t$	V_s =	23,018	ft^3

Step 5: Calculate underdrain system			
5-1. Calculated filtered flow rate, $Q_f = (r_{wq}A_{sf})/86400$	Q_f =	0.10	cfs
5-2. Enter minimum slope for energy gradient, S_e	S_e =	0.005	
5-3. Enter Hazen-Williams coefficient for plastic, C	C =	140	
5-4. Enter pipe diameter, D	D =	6	in
5-5. Calculate pipe hydraulic radius, $R_h = D/48$	R_h =	0.13	
5-6. Calculate velocity at the outlet of the pipe, $V_p = 1.318CR_h^{0.63}S_e^{0.54}$	V_p =	2.8	ft/s
5-7. Calculate pipe capacity, $Q_{cap} = 0.25\pi(D/12)^2V_p$	Q_{cap} =	0.6	cfs

Step 6: Provide conveyance capacity for filter clogging
6-1.The sand filters should be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged and **verify that all parameters meet design requirements** to complete sizing.

Sand Filter Design Example

Step 1: Calculate the Design Flow

For this design example, a 10-acre residential development with a 60% total impervious area is considered. Flow-based sizing, as described in Appendix C, is assumed. Therefore, the design rainfall intensity is assumed to be 0.25 in/hr.

Step 1: Calculate the design flow			
1-1. Enter drainage area, A	A =	10	acres
1-2. Enter impervious fraction, Imp	Imp =	0.60	
1-3. Calculate runoff coefficient, C = (0.9•Imp + 0.05)	C =	0.59	
1-4. Calculate the water quality design flow rate, Q_{wq}, based on a constant rainfall intensity of 0.25 in/hr, Appendix C	Q_{wq} =	1.48	cfs

Step 2: Calculate Sand Filter Area

A sand filter is designed with two components: (1) temporary storage reservoir to store runoff, and (2) a sand filter bed through which the stored runoff must percolate getting treatment. The simple sizing method does not rout flows through the filter. The size of the filter is determined based on the simple assumption that inflow is immediately discharged through the filter. The adjustment factor, R, is applied to compensate for the greater filter size resulting from this method.

Step 2: Calculate sand filter area			
2-1. Enter thickness of sand filter (min. 24" or 2'), l	l =	2	ft
2-2. Enter maximum storage depth (6 feet) above the filter, d	d =	6	ft
2-3. Enter routing adjustment factor, R	R =	0.7	
2-4. Calculate average depth of water above the filter, h = d/2	h =	3	ft
2-5. Enter hydraulic conductivity (1"/hr), K_i	K_i =	1	in/hr
2-6. Calculate hydraulic conductivity (ft/day), $K_{day} = 2K_i$	K_{day} =	2	ft/day
2-7. Calculate hydraulic gradient, i = (h+l)/l	i =	2.5	ft/ft
2-8. Enter drawdown time, t	t =	2	day
2-9. Calculate sand filter area, $A_{sf} = (V_{wq}Rl)/(K_{day}t(h+l))$	A_{sf} =	1,799	ft^2

Step 3: Determine Filter Dimensions

Step 3: Determine filter dimensions			
3-1. Sand filter area, A_{sf}	A_{sf} =	1,799	ft^2
3-2. Enter geometric configuration, L_R:W ratio (2:1), L_R	L_R =	2	
3-3. Calculate the width of the sand filter, W	W =	30.0	ft
3-4. Calculate the length of the sand filter, L	L =	60.0	ft
3-5. Calculate rate of filtration, $r_{wq} = K_{day}i$	r_{wq} =	5.0	$ft/d/ft^2$

Step 4: Calculate Storage Volume

The side slopes are will be designed as 3H:1V, so Z = 3.

Step 4: Calculate storage volume			
4-1. Enter interior side slopes, 3H:1V (max), Z	Z =	3	
4-2. Calculate top length, $L_t = L + 2Zd$	L_t =	96.0	ft
4-3. Calculate top width, $W_t = W + 2Zd$	W_t =	66.0	ft
4-4. Calculate filter storage volume, $V_s = 1/3 \bullet d(A_{sf}+A_t+(A_{sf}A_t)^{0.5})$ where $A_t = L_t \bullet W_t$	V_s =	23,018	ft^3

Step 5: Calculate Underdrain System

All underdrain pipes must be 6 inches or greater to facilitate cleaning.

Step 5: Calculate underdrain system			
5-1. Calculated filtered flow rate, $Q_f = (r_{wq}A_{sf})/86400$	Q_f =	0.10	cfs
5-2. Enter minimum slope for energy gradient, S_e	S_e =	0.005	
5-3. Enter Hazen-Williams coefficient for plastic, C	C =	140	
5-4. Enter pipe diameter, D	D =	6	in
5-5. Calculate pipe hydraulic radius, $R_h = D/48$	R_h =	0.13	
5-6. Calculate velocity at the outlet of the pipe, $V_p = 1.318CR_h^{0.63}S_e^{0.54}$	V_p =	2.8	ft/s
5-7. Calculate pipe capacity, $Q_{cap} = 0.25\pi(D/12)^2V_p$	Q_{cap} =	0.6	cfs

Step 6: Provide Conveyance Capacity for Filter Clogging

The sand filters should be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged and **verify that all parameters meet design requirements** to complete sizing.

Infiltration BMP Worksheet

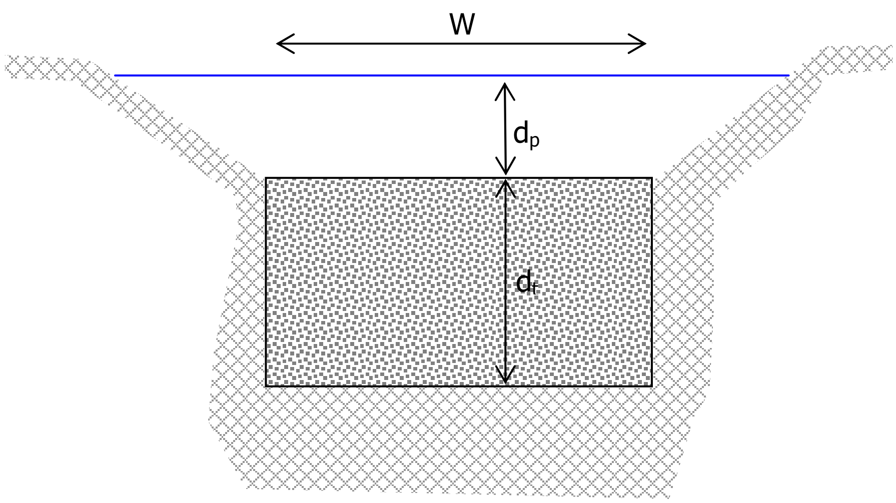

Figure D-5: Infiltration BMP cross-section

Refer to Figures D-5, 6-12, 6-13 and 6-14 for a diagrammatic description of the geometric variables.

Step 1: Determine design volume reduction, $V_{reduction}$	
1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25}, calculated using SBUH method, Appendix C	V_{25} = __________ ft^3
1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one\text{-}inch}$, calculated using SBUH method, Appendix C	$V_{one\text{-}inch}$ = __________ ft^3
1-3. Determine design volume reduction which is the larger of V_{25} and $V_{one\text{-}inch}$ and is the volume to be retained on-site	$V_{reduction}$ = __________ ft^3
Step 2: Determine storm water quality design volume, V_{wq}	
2-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (<u>Note</u>: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} = __________ ft^3
Step 3: Determine design volume, V_{design} (for sizing)	
3-1. V_{design} = the larger of $V_{reduction}$ and V_{wq}	V_{design} = __________ ft^3

Step 4: Calculate design infiltration rate			
4-1. Enter soil infiltration rate (0.5 in/hr min.), $k_{measured}$	$k_{measured}$ =	______	in/hr
4-2. Enter correction factor for testing (0.3 small scale, 0.5 large scale), F_t	F_t =	______	ft
4-3. Enter correction factor for plugging, (0.7 loams-sandy loams, 0.8 fine-loamy sands, 0.9 medium sands, 1.0 coarse sands-cobbles, F_p	F_p =	______	
4-4. Enter the depth from the bottom of the facility to the maximum wet-season water table or nearest impervious layer, whichever is less. D	D =	______	ft
4-5. Enter the estimated width of the facility	W =	______	ft
4-6. Calculate the correction factor of geometry (0.25 min, 1.0 max), Fg = 4•D/W +0.05	F_g =	______	
4-7. Calculate the design infiltration rate, $k_{design}=k_{measured}F_tF_pF_g$	k_{design} =	______	in/hr
Step 5: Determine facility size			
5-1. Enter drawdown time(72 hrs max.), t_d	t_d =	______	hrs
5-2. Calculate max.depth of runoff that can be infiltrated within the $t_{d,}$ $d_{max}=k_{design}t_d/12$	d_{max}=	______	ft
5-3. Enter trench fill aggregate porosity, n_t	n_t=	______	
5-4. Enter depth of trench fill, d_t	d_t =	______	in
5-5. Enter max ponding depth, or max. $d_p=d_{max}-n_td_t$	d_p=	______	ft
Step 6: Determine infiltrating surface area (filter bottom area)			
6-1. Enter the time to fill infiltration basin or trench with water (Use 2 hours for most designs), T	T =	______	hrs
6-2. Calculate infiltrating surface area for infiltration basin: $A_b=V_{design}/((Tk_{design}/12)+d_p)$	A_b =	______	ft^2
6-3. Calculate infiltrating surface area for infiltration trenches: $A_t=V_{design}/((Tk_{design}/12)+n_td_t+dp)$	A_t =	______	ft^2
6-4. Calculate infiltrating surface area for dry wells: $A_{dw}=V_{design}/(Tk_{design}/12)+n_td_t))$	A_{dw} =	______	ft^3
Step 7: Provide conveyance capacity for filter clogging			
7-1.The infiltration facility should be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged.			

Infiltration BMP Design Example

Step 1: Determine Storm Water Quality Design Volume Reduction, $V_{reduction}$

Step 1: Determine design volume reduction, $V_{reduction}$			
1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25}, calculated using SBUH method, Appendix C	V_{25} =	20	ft^3
1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one\text{-}inch}$, calculated using SBUH method, Appendix C	$V_{one\text{-}inch}$ =	25,700	ft^3
1-3. Determine design volume reduction which is the larger of V_{25} and $V_{one\text{-}inch}$ and is the volume to be retained on-site	$V_{reduction}$ =	25,700	ft^3

Step 2: Determine Storm Water Quality Design Volume, V_{wq}

Step 2: Determine storm water quality design volume, V_{wq}			
2-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} =	25,700	ft^3

Step 3: Determine Design Volume, V_{design}

Step 3: Determine design volume, V_{design} (for sizing)			
3-1. V_{design} = the larger of $V_{reduction}$ and V_{wq}	V_{design} =	25,700	ft^3

Step 4: Calculate Design Infiltration Rate

Infiltration facilities require a minimum soil infiltration rate of 0.5 in/hr. If the rate exceeds 2.4 in/hr, then the runoff should be fully treated in an upstream BMP prior to infiltration to protect the groundwater quality.

The factors applied to in-situ measured infiltration rate take into account uncertainty in measures, depth of water, geometry and long term reductions in permeability due to biofouling and fines accumulation. A small scale testing factor has been assigned to this example. Since the soils in the residential development have been designated as loamy sands, a plugging factor of 0.8 should be used. If the depth from the bottom of the site to the maximum water table is 10 ft and there is space to create the infiltration facility at roughly 60 ft wide, then the correction factor of geometry can be calculated as 0.72.

Step 4: Calculate design infiltration rate			
4-1. Enter soil infiltration rate (0.5 in/hr min.), $k_{measured}$	$k_{measured}$ =	4	in/hr
4-2. Enter correction factor for testing (0.3 small scale, 0.5 large scale), F_t	F_t =	0.3	ft
4-3. Enter correction factor for plugging, (0.7 loams-sandy loams, 0.8 fine-loamy sands, 0.9 medium sands, 1.0 coarse sands-cobbles, F_p	F_p =	0.8	
4-4. Enter the depth from the bottom of the facility to the maximum wet-season water table or nearest impervious layer, whichever is less. D	D =	10	ft
4-5. Enter the estimated width of the facility	W =	60	ft
4-6. Calculate the correction factor of geometry (0.25 min, 1.0 max), Fg = 4•D/W +0.05	F_g =	0.72	
4-7. Calculate the design infiltration rate, $k_{design}=k_{measured}F_tF_pF_g$	k_{design} =	0.69	in/hr

Step 5: Determine Facility Size

The simple sizing method requires that the water quality volume must be completely infiltrated within 72 hours. The size of the filter is determined based on the simple assumption that inflow is immediately discharged through the filter.

Step 5: Determine facility size			
5-1. Enter drawdown time(72 hrs max.), t_d	t_d =	72	hrs
5-2. Calculate max.depth of runoff that can be infiltrated within the t_d, $d_{max}=k_{design}t_d/12$	d_{max}=	4.13	ft
5-3. Enter trench fill aggregate porosity, n_t	n_t=	0.35	
5-4. Enter depth of trench fill, d_t	d_t =	48	in
5-5. Enter max ponding depth, or max. $d_p=d_{max}-n_td_t$	d_p=	2.73	ft

Step 6: Determine Infiltrating Surface Area

The size of the infiltrating surface is determined by assuming the water quality design volume will fill the available ponding depth plus the void spaces of the computed porosity (usually about 32%) of the filter media.

Step 6: Determine infiltrating surface area (filter bottom area)			
6-1. Enter the time to fill infiltration basin or trench with water (Use 2 hours for most designs), T	T =	2	hrs
6-2. Calculate infiltrating surface area for infiltration basin: $A_b = V_{design}/((Tk_{design}/12)+d_p)$	A_b =	9,041	ft^2
6-3. Calculate infiltrating surface area for infiltration trenches: $A_t = V_{design}/((Tk_{design}/12)+n_t d_t+dp)$	A_t =	1,308	ft^2
6-4. Calculate infiltrating surface area for dry wells: $A_{dw} = V_{design}/(Tk_{design}/12)+n_t d_t))$	A_{dw} =	1,519	ft^3

Step 7: Provide Conveyance Capacity for Flows Higher than Q_{wq}

The infiltration facility should be placed off-line, but an emergency overflow for flows greater than the water quality peak flow rate, Q_{wq}, must still be provided in the event the filter becomes clogged.

Permeable Pavement Worksheet

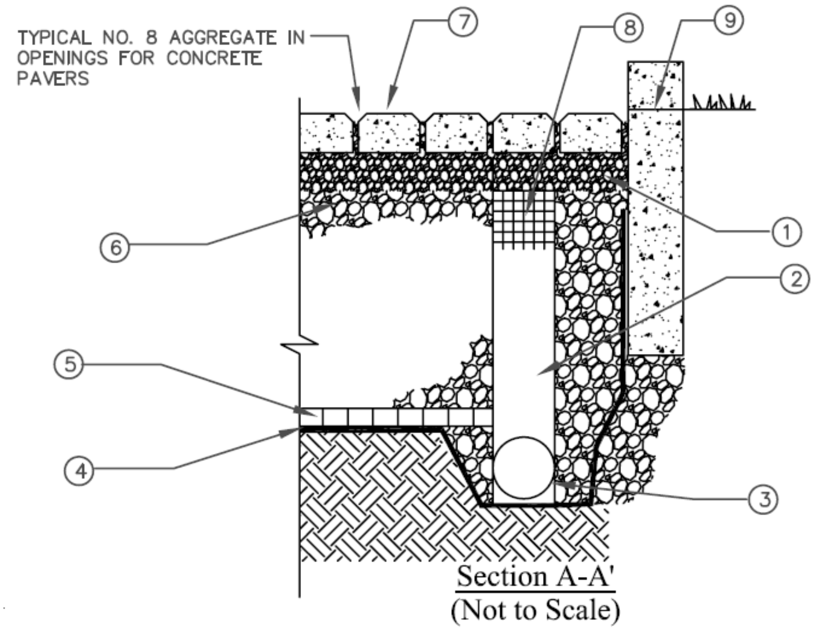

Figure D-6: Permeable Pavement cross-section

Refer to Figures D-6 and Figure 6-16 for a diagrammatic description of the geometric variables.

Step 1: Determine design volume reduction, $V_{reduction}$	
1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25}, calculated using SBUH method, Appendix C	V_{25} = 32,000 ft^3
1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one\text{-}inch}$, calculated using SBUH method, Appendix C	$V_{one\text{-}inch}$ = 25,700 ft^3
1-3. Determine design volume reduction which is the larger of V_{25} and $V_{one\text{-}inch}$ and is the volume to be retained on-site	$V_{reduction}$ = 32,000 ft^3
Step 2: Determine storm water quality design volume, V_{wq}	
2-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (<u>Note</u>: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} = 25,700 ft^3
Step 3: Determine design volume, V_{design} (for sizing)	
3-1. If no infiltration (i.e., impermeable liner w/ underdrains), $V_{design} = V_{wq}$.	V_{design} = 25,700 ft^3
3-2. If partial infiltration (i.e., permeable liner w/underdrains), $V_{design} = V_{wq}+0.2V_{wq}$	V_{design} = 30,840 ft^3
3-3. If full infiltration (i.e., permeable liner w/ no underdrains), $V_{design} = V_{reduction}$	V_{design} = 32,000 ft^3

Step 4: Calculate design infiltration rate (assume full infiltration, $V_{design} = V_{reduction}$)			
4-1. Enter soil infiltration rate (0.5 in/hr min.), $k_{measured}$	$k_{measured}$ =	3	in/hr
4-2. Enter correction factor for testing (0.3 small scale, 0.5 large scale), F_t	F_t =	0.3	ft
4-3. Enter correction factor for plugging, (0.7 loams-sandy loams, 0.8 fine-loamy sands, 0.9 medium sands, 1.0 coarse sands-cobbles, F_p	F_p =	0.8	
4-4. Enter the depth from the bottom of the facility to the maximum wet-season water table or nearest impervious layer, whichever is less. D	D =	10	ft
4-5. Enter the estimated width of the facility	W =	60	ft
4-6. Calculate the correction factor of geometry (0.25 min, 1.0 max), Fg = 4•D/W +0.05	F_g =	0.72	
4-7. Calculate the design infiltration rate, $k_{design}=k_{measured}F_tF_pF_g$	k_{design} =	0.52	in/hr
Step 5: Determine maximum depth that can be infiltrated			
5-1. Enter drawdown time (72 hrs max.), t	t =	72	hrs
5-2. Calculate max.depth of runoff that can be infiltrated within the t, $d_{max}=k_{design}t/12$	d_{max}=	3.10	ft
Step 6: Determine infiltrating surface area (gravel drainage area)			
6-1. Enter gravel drainage layer porosity, n	n=	0.32	
6-2. Enter depth of gravel drainage layer, l	l =	48.00	in
6-3. Enter the time to fill the gravel drainage layer with water (Use 2 hours for most designs), T	T =	2	hrs
6-4. Calculate infiltrating surface area for dry wells: $A=V_{design}/(Tk_{design}/12)+n*l))$	A =	2,072	ft^3
Step 7: Provide conveyance capacity for filter clogging			
7-1.The permeable pavement must have an emergency overflow for storm events greater than the design and in the event the permeable pavement becomes clogged.			

Permeable Pavement Design Example

Step 1: Determine Storm Water Quality Design Volume Reduction, $V_{reduction}$

Step 1: Determine design volume reduction, $V_{reduction}$	
1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25}, calculated using SBUH method, Appendix C	V_{25} = 20 ft^3
1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one\text{-}inch}$, calculated using SBUH method, Appendix C	$V_{one\text{-}inch}$ = 25,700 ft^3
1-3. Determine design volume reduction which is the larger of V_{25} and $V_{one\text{-}inch}$ and is the volume to be retained on-site	$V_{reduction}$ = 25,700 ft^3

Step 2: Determine Storm Water Quality Design Volume, V_{wq}

Step 2: Determine storm water quality design volume, V_{wq}	
2-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} = 25,700 ft^3

Step 3: Determine Design Volume, V_{design}

Step 3: Determine design volume, V_{design} (for sizing)	
3-1. If no infiltration (i.e., impermeable liner w/ underdrains), $V_{design} = V_{wq}$.	V_{design} = ______ ft^3
3-2. If partial infiltration (i.e., permeable liner w/underdrains), $V_{design} = V_{wq}+0.2V_{wq}$	V_{design} = ______ ft^3
3-3. If full infiltration (i.e., permeable liner w/ no underdrains), $V_{design} = V_{reduction}$	V_{design} = ______ ft^3

Step 4: Calculate Design Infiltration Rate (assuming full infiltration)

Permeable pavement with no underdrain requires a minimum soil infiltration rate of 0.5 in/hr.

The factors applied to in-situ measured infiltration rate take into account uncertainty in measures, depth of water, geometry and long term reductions in permeability due to biofouling and fines accumulation. A small scale testing factor has been assigned to this example. Since the soils in the residential development have been designated as loamy sands, a plugging factor of 0.8 should be used. If the depth from the bottom of the site to the maximum water table is 10 ft and there is space to create the infiltration facility at roughly 60 ft wide, then the correction factor of geometry can be calculated as 0.72.

Step 4: Calculate design infiltration rate (assume full infiltration, $V_{design} = V_{reduction}$)			
4-1. Enter soil infiltration rate (0.5 in/hr min.), $k_{measured}$	$k_{measured}$ =	3	in/hr
4-2. Enter correction factor for testing (0.3 small scale, 0.5 large scale), F_t	F_t =	0.3	ft
4-3. Enter correction factor for plugging, (0.7 loams-sandy loams, 0.8 fine-loamy sands, 0.9 medium sands, 1.0 coarse sands-cobbles, F_p	F_p =	0.8	
4-4. Enter the depth from the bottom of the facility to the maximum wet-season water table or nearest impervious layer, whichever is less. D	D =	10	ft
4-5. Enter the estimated width of the facility	W =	60	ft
4-6. Calculate the correction factor of geometry (0.25 min, 1.0 max), Fg = 4•D/W +0.05	F_g =	0.72	
4-7. Calculate the design infiltration rate, $k_{design}=k_{measured}F_tF_pF_g$	k_{design} =	0.52	in/hr

Step 5: Determine maximum depth that can be infiltrated

Step 5: Determine maximum depth that can be infiltrated			
5-1. Enter drawdown time (72 hrs max.), t	t =	72	hrs
5-2. Calculate max.depth of runoff that can be infiltrated within the t, $d_{max}=k_{design}t/12$	d_{max}=	3.10	ft

Step 6: Determine the infiltrating surface area (gravel drainage area)

Step 6: Determine infiltrating surface area (gravel drainage area)			
6-1. Enter gravel drainage layer porosity, n	n=	0.32	
6-2. Enter depth of gravel drainage layer, l	l =	48.00	in
6-3. Enter the time to fill the gravel drainage layer with water (Use 2 hours for most designs), T	T =	2	hrs
6-4. Calculate infiltrating surface area for dry wells: $A=V_{design}/(Tk_{design}/12)+n*l))$	A =	2,072	ft^3

Step 7: Determine maximum depth that can be infiltrated

Step 7: Provide conveyance capacity for filter clogging
7-1.The permeable pavement must have an emergency overflow for storm events greater than the design and in the event the permeable pavement becomes clogged.

Constructed Treatment Wetland Worksheet

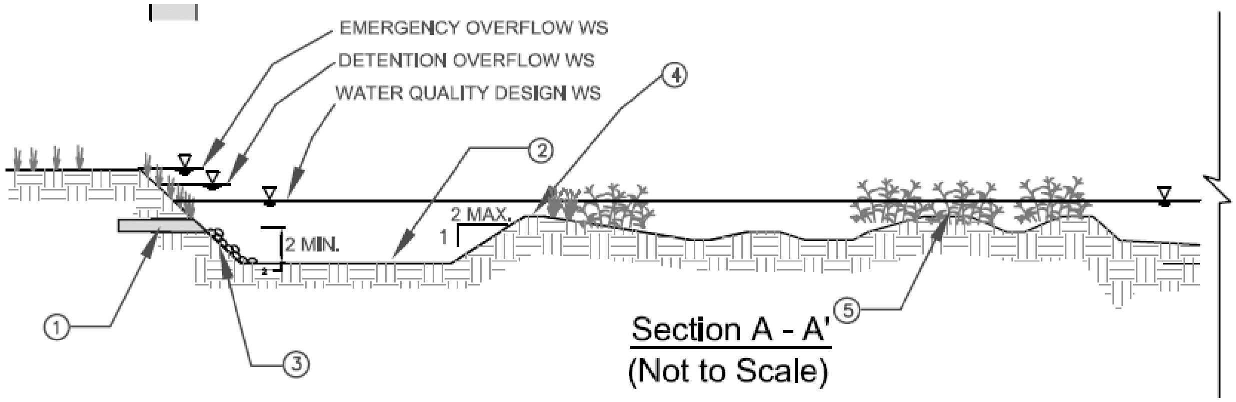

Figure D-7: Constructed treatment wetland cross-section

Refer to Figures D-6 and 6-22 for a diagrammatic description of the geometric variables.

Step 1: Determine storm water quality design volume, V_{wq}	
1-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} = __________ ft^3

Step 2: Determine Wetland Location, Wetland Type and Preliminary Geometry Based on Site Constraints		
2-1. Based on site constraints, determine the wetland geometry and the storage available by developing an elevation-storage relationship for the wetland. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2. The wetland does not have extended detention.		
2-2. Enter the total surface area of the wetland footprint based on site constraints, A_{tot}	A_{tot} = ________	ft^2
2-3. Enter the length of the wetland footprint based on site constraints, L_{tot}	L_{tot} = ________	ft
2-4. Calculate the width of the wetland footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} = ________	ft
2-5. Enter interior side slope as length per unit height (min = 3), Z	Z = ________	
2-6. Enter desired freeboard depth, d_{fb}	d_{fb} = ________	ft
2-7. Calculate the length of the water quality surface area including the internal berm but excluding freeboard, $L_{wq\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{wq\text{-}tot}$ = ________	ft
2-8. Calculate the width of the water quality surface area including the internal berm but excluding freeboard, $W_{wq\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{wq\text{-}tot}$ = ________	ft
2-9. Calculate the total water quality surface area including the internal berm and excluding freeboard, $A_{wq\text{-}tot} = L_{wq\text{-}tot} \cdot W_{wq\text{-}tot}$	$A_{wq\text{-}tot}$ = ________	ft^2
2-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} = ________	ft
2-11. Enter the length of the internal berm, $L_{berm} = W_{wq\text{-}tot}$	L_{berm} = ________	ft
2-12. Calculate the area of the berm, $A_{berm} = W_{berm} \cdot L_{berm}$	A_{berm} = ________	ft^2
2-13. Calculate the active volume surface area excluding the internal berm and freeboard, $A_{wq} = A_{wq\text{-}tot} - A_{berm}$	A_{wq} = ________	ft^2
Step 3: Determine Dimensions of Cell 1		
3-1. Enter the percent of V_{wq} in Cell 1 (10-20% required), $\%V_1$	$\%V_1$ = ________	%
3-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_{wq} \cdot \%V_1)/100$	V_1 = ________	ft^3
3-3. Enter desired average depth of Cell 1 (5-9 ft including sediment storage of 1 ft), d_1	d_1 = ________	ft
3-4. Calculate the surface area for the water quality volume of Cell 1, $A_1 = V_1 / d_1$	A_1 = ________	ft^2
3-5. Enter the width of Cell 1, $W_1 = W_{av\text{-}tot} = L_{berm}$	W_1 = ________	ft
3-6. Calculate the length of Cell 1 (<u>Note:</u> inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W1$	L_1 = ________	ft

Step 4: Determine Dimensions of Cell 2			
4-1. Calculate the active volume of Cell 2, $V_2 = V_{wq} - V_1$	V_2 =	________	ft^3
4-2. Calculate surface area of Cell 2, $A_2 = A_{wq} - A_1$	A_2 =	________	ft^2
4-3. Enter width of Cell 2, $W_2 = W_1 = W_{wq\text{-}tot} = L_{berm}$	W_2 =	________	ft
4-4. Calculate top length of Cell 2, $L_2 = A_2 / W_2$	L_2 =	________	ft
4-5. Verify that the length-to-width ratio of Cell 2 is at least 3:1 with ≥ 4:1 preferred. If the length-to-width ratio is less than 3:1, modify input parameters until a ratio of at least 3:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$	LW_2 =	________	
4-6. Enter percent of surface area of very shallow zone, $\%A_{vs}$	$\%A_{vs}$ =	________	ft^2
4-7. Calculate very shallow zone surface area, $A_{vs} = (A_2 \bullet \%A_{vs})/100$	A_{vs} =	________	ft^2
4-8. Enter average depth of very shallow zone (0.1 - 1 ft), d_{vs}	d_{vs} =	________	ft
4-9. Calculate volume of very shallow zone, $V_{vs} = A_{vs} \bullet d_{vs}$	V_{vs} =	________	ft^3
4-10. Enter width of very shallow zone, $W_{vs} = W_2$	W_{vs} =	________	ft
4-11. Calculate length of very shallow zone, $L_{vs} = A_{vs} / W_{vs}$	L_{vs} =	________	ft
4-12. Enter percent of surface area of shallow zone, $\%A_s$	$\%A_s$ =	________	
4-13. Calculate surface area of shallow zone, $A_s = (A_2 \bullet \%A_s)/100$	A_s =	________	ft^2
4-14. Enter average depth of shallow zone (1 - 3 ft), d_s	d_s =	________	ft
4-15. Calculate volume of shallow zone, $V_s = A_s \bullet d_s$	V_s =	________	ft^3
4-16. Enter width of shallow zone, $W_s = W_2$	W_s =	________	ft
4-17. Calculate length of shallow zone, $L_s = A_s / W_s$	L_s =	________	ft
4-18. Calculate surface area of deep zone, $A_{deep} = A_2 - A_{vs} - A_s$	A_{deep} =	________	ft^2
4-19. Calculate volume of deep zone, $V_{deep} = V_2 - V_{vs} - V_s$	V_{deep} =	________	ft^3
4-20. Calculate average depth of deep zone (3 - 5 ft), $d_{deep} = V_{deep} / A_{deep}$	d_{deep} =	________	ft
4-21. Enter width of deep zone, $W_{deep} = W_2$	W_{deep} =	________	ft
4-22. Calculate length of deep zone, $L_{deep} = A_{deep} / W_{deeo}$	L_{deep} =	________	ft
Step 5: Ensure Design Requirements and Site Constraints are Achieved			
5-1. Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the wetland is inadequate to meet the design requirements, choose a new location for the wetland.			
Step 6: Size Outlet Structure			
6-1. Please refer to Appendix D for outlet structure sizing methodologies and examples. The wetland outlet pipe shall be sized, at a minimum, to pass flows greater than the water quality design peak flow for off-line basins or flow from the capital storm for on-line basins.			

Step 7: Determine Emergency Spillway Requirements	
7-1. For online basins, an emergency overflow spillway should be sized to pass the capital design storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.	

Constructed Treatment Wetland Design Example

Wetland siting requires the following considerations prior to construction: (1) availability of base flow – storm water wetlands require a regular source of water to support wetland biota, (2) slope stability – storm water wetlands are not permitted near steep slope hazard areas, (3) surface space availability – large footprint area is required, and (4) compatibility with flood control – basins must not interfere with flood control functions of existing conveyance and detention structures.

The wetland in this example does not have extended detention. An internal berm separates the forebay (Cell 1) and the main basin (Cell 2). The berm is at the elevation of the active volume design surface which is also the permanent wetpool elevation.

Step 1: Determine Water Quality Design Volume

For this design example, a 10-acre residential development with a 60% total impervious area is considered.

Step 1: Determine storm water quality design volume, V_{wq}	
1-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (<u>Note</u>: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} = 27,500 ft^3

Step 2: Determine Pond Location and Preliminary Geometry Based on Site Constraints

A total footprint area and total length available for the wetland is provided. This step calculates the total active volume surface area which is equivalent to the permanent wetpool surface area. This step also calculates the dimensions of the internal berm.

Step 2: Determine Wetland Location, Wetland Type and Preliminary Geometry Based on Site Constraints			
2-1. Based on site constraints, determine the wetland geometry and the storage available by developing an elevation-storage relationship for the wetland. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2. The wetland does not have extended detention.			
2-2. Enter the total surface area of the wetland footprint based on site constraints, A_{tot}	A_{tot} =	11,000	ft^2
2-3. Enter the length of the wetland footprint based on site constraints, L_{tot}	L_{tot} =	200	ft
2-4. Calculate the width of the wetland footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} =	55	ft
2-5. Enter interior side slope as length per unit height (min = 3), Z	Z =	3	
2-6. Enter desired freeboard depth, d_{fb}	d_{fb} =	2	ft
2-7. Calculate the length of the water quality surface area including the internal berm but excluding freeboard, $L_{wq\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{wq\text{-}tot}$ =	188	ft
2-8. Calculate the width of the water quality surface area including the internal berm but excluding freeboard, $W_{wq\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{wq\text{-}tot}$ =	43	ft
2-9. Calculate the total water quality surface area including the internal berm and excluding freeboard, $A_{wq\text{-}tot} = L_{wq\text{-}tot} \bullet W_{wq\text{-}tot}$	$A_{wq\text{-}tot}$ =	8,084	ft^2
2-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} =	6	ft
2-11. Enter the length of the internal berm, $L_{berm} = W_{wq\text{-}tot}$	L_{berm} =	43	ft
2-12. Calculate the area of the berm, $A_{berm} = W_{berm} \bullet L_{berm}$	A_{berm} =	258	ft^2
2-13. Calculate the active volume surface area excluding the internal berm and freeboard, $A_{wq} = A_{wq\text{-}tot} - A_{berm}$	A_{wq} =	7,826	ft^2

Step 3: Determine Dimensions of Cell 1

It should be assumed that cell 1 (the forebay) should be 15% of the water quality design volume, V_{wq}.

Step 3: Determine Dimensions of Cell 1			
3-1. Enter the percent of V_{wq} in Cell 1 (10-20% required), $\%V_1$	$\%V_1$ =	15	%
3-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_{wq} \cdot \%V_1)/100$	V_1 =	4,125	ft^3
3-3. Enter desired average depth of Cell 1 (5-9 ft including sediment storage of 1 ft), d_1	d_1 =	5	ft
3-4. Calculate the surface area for the water quality volume of Cell 1, $A_1 = V_1 / d_1$	A_1 =	825	ft^2
3-5. Enter the width of Cell 1, $W_1 = W_{av\text{-}tot} = L_{berm}$	W_1 =	43	ft
3-6. Calculate the length of Cell 1 (Note: inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W1$	L_1 =	19	ft

Step 4: Determine Dimensions of Cell 2

Verify that the surface area and length-to-width ratio of Cell 2 meet the design criteria. Calculate volumes, depths, and surface areas for the very shallow, shallow and deep zones.

Step 4: Determine Dimensions of Cell 2			
4-1. Calculate the active volume of Cell 2, $V_2 = V_{wq} - V_1$	V_2 =	23,375	ft^3
4-2. Calculate surface area of Cell 2, $A_2 = A_{wq} - A_1$	A_2 =	7,001	ft^2
4-3. Enter width of Cell 2, $W_2 = W_1 = W_{wq\text{-}tot} = L_{berm}$	W_2 =	43	ft
4-4. Calculate top length of Cell 2, $L_2 = A_2 / W_2$	L_2 =	163	ft
4-5. Verify that the length-to-width ratio of Cell 2 is at least 3:1 with ≥ 4:1 preferred. If the length-to-width ratio is less than 3:1, modify input parameters until a ratio of at least 3:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$	LW_2 =	4	
4-6. Enter percent of surface area of very shallow zone, $\%A_{vs}$	$\%A_{vs}$ =	15	ft^2
4-7. Calculate very shallow zone surface area, $A_{vs} = (A_2 \cdot \%A_{vs})/100$	A_{vs} =	1,050	ft^2
4-8. Enter average depth of very shallow zone (0.1 - 1 ft), d_{vs}	d_{vs} =	1	ft
4-9. Calculate volume of very shallow zone, $V_{vs} = A_{vs} \cdot d_{vs}$	V_{vs} =	1,050	ft^3
4-10. Enter width of very shallow zone, $W_{vs} = W_2$	W_{vs} =	43	ft
4-11. Calculate length of very shallow zone, $L_{vs} = A_{vs} / W_{vs}$	L_{vs} =	24	ft
4-12. Enter percent of surface area of shallow zone, $\%A_s$	$\%A_s$ =	55	
4-13. Calculate surface area of shallow zone, $A_s = (A_2 \cdot \%A_s)/100$	A_s =	3,851	ft^2
4-14. Enter average depth of shallow zone (1 - 3 ft), d_s	d_s =	3	ft
4-15. Calculate volume of shallow zone, $V_s = A_s \cdot d_s$	V_s =	11,552	ft^3

4-16. Enter width of shallow zone, $W_s = W_2$	$W_s =$	43	ft
4-17. Calculate length of shallow zone, $L_s = A_s / W_s$	$L_s =$	90	ft
4-18. Calculate surface area of deep zone, $A_{deep} = A_2 - A_{vs} - A_s$	$A_{deep} =$	2,100	ft^2
4-19. Calculate volume of deep zone, $V_{deep} = V_2 - V_{vs} - V_s$	$V_{deep} =$	10,773	ft^3
4-20. Calculate average depth of deep zone (3 - 5 ft), $d_{deep} = V_{deep} / A_{deep}$	$d_{deep} =$	5	ft
4-21. Enter width of deep zone, $W_{deep} = W_2$	$W_{deep} =$	43	ft
4-22. Calculate length of deep zone, $L_{deep} = A_{deep} / W_{deeo}$	$L_{deep} =$	49	ft

Step 5: Ensure Design Requirements and Site Conditions are Achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the wetland is inadequate to meet the design requirements, choose a new location for the wetland.

Step 6: Size Outlet Structure

Please refer to Appendix E for wetland outlet structure sizing methodologies and examples. The wetland outlet pipe shall be sized, at a minimum, to pass flows greater than the water quality design peak flow for off-line basins or flow from the capital storm for on-line basins.

Step 7: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass the capital design storm to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Wet Retention Basin Worksheet

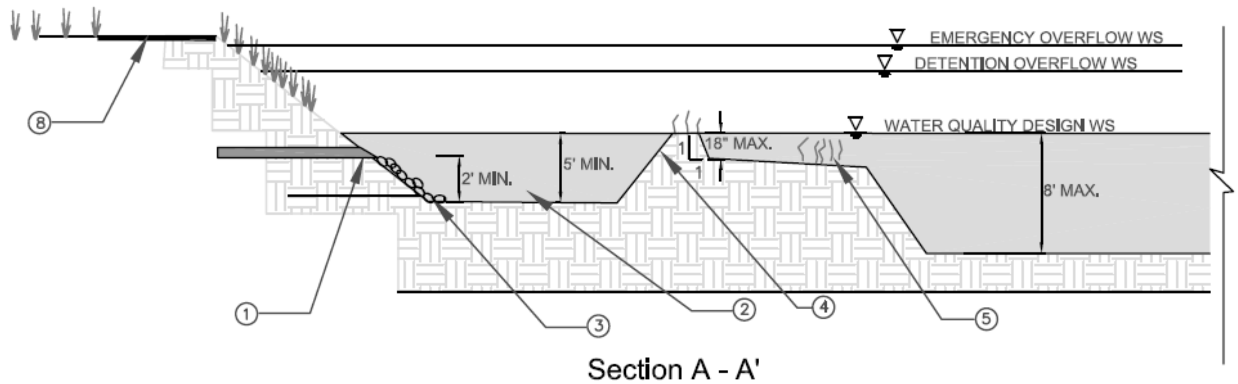

Figure D-8: Wet Retention Basin cross-section

Refer to D-7 and Figure 6-24 for a diagrammatic description of the geometric variables.

Step 1: Determine storm water quality design volume, V_{wq}	
1-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (<u>Note</u>: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} = _________ ft^3
Step 2: Determine Active Design Volume for the Wet Pond without Extended Detention	
2-1. Calculate the active design volume (without extended detention), V_a = $1.05V_{wq}$	V_a = _________ ft^3

Step 3: Determine Pond Location and Preliminary Geometry Based on Site Constraints		
3-1. Based on site constraints, determine the pond geometry and the storage available by developing an elevation-storage relationship for the pond. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2.		
3-2. Enter the total surface area of the pond footprint based on site constraints, A_{tot}	A_{tot} = ________	ft^2
3-3. Enter the length of the pond footprint based on site constraints, L_{tot}	L_{tot} = ________	ft
3-4. Calculate the width of the pond footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} = ________	ft
3-5. Enter interior side slope as length per unit height (min = 3), Z	Z = ________	
3-6. Enter desired freeboard depth, d_{fb}	d_{fb} = ________	ft
3-7. Calculate the length of the active volume surface area including the internal berm but excluding freeboard, $L_{av\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{av\text{-}tot}$ = ________	ft
3-8. Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{av\text{-}tot}$ = ________	ft
3-9. Calculate the total water quality surface area including the internal berm and excluding freeboard, $A_{av\text{-}tot} = L_{av\text{-}tot} \bullet W_{av\text{-}tot}$	$A_{av\text{-}tot}$ = ________	ft^2
3-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} = ________	ft
3-11. Enter the length of the internal berm, $L_{berm} = W_{av\text{-}tot}$	L_{berm} = ________	ft
3-12. Calculate the area of the berm, $A_{berm} = W_{berm} \bullet L_{berm}$	A_{berm} = ________	ft^2
3-13. Calculate the active volume surface area excluding the internal berm and freeboard, $A_{av} = A_{av\text{-}tot} - A_{berm}$	A_{av} = ________	ft^2
Step 4: Determine Dimensions of Cell 1		
4-1. Enter the percent of V_a in Cell 1, $\%V_1$	$\%V_1$ = ________	%
4-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_a \bullet \%V_1)/100$	V_1 = ________	ft^3
4-3. Enter desired average depth of Cell 1 (5-9 ft including sediment storage of 1 ft), d_1	d_1 = ________	ft
4-4. Calculate the surface area for the active volume of Cell 1, $A_1 = V_1 / d_1$	A_1 = ________	ft^2
4-5. Enter the width of Cell 1, $W_1 = W_{av\text{-}tot} = L_{berm}$	W_1 = ________	ft
4-6. Calculate the length of Cell 1 (Note: inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W1$	L_1 = ________	ft

Step 5: Determine Dimensions of Cell 2			
5-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$	V_2 =	________	ft^3
5-2. Determine <u>minimum</u> wetpool surface area, $A_{min2} = V_2 \bullet 0.3$	A_{min2} =	________	ft^2
5-3. Determine actual wetpool surface area, $A_2 = A_{av} - A_1$	A_2 =	________	ft^2
5-4. If A_2 is greater than A_{min2} then move on to step 5-5. If A_2 is less than A_{min2}, then modify input parameters to increase A_2 until it is greater than A_{min2}. If site constraints limit this criterion, then another site for the pond should be chosen.			
5-5. Enter width of Cell 2, $W_2 = W_1 = W_{av\text{-}tot} = L_{berm}$	W_2 =	________	ft
5-6. Calculate top length of Cell 2, $L_2 = A_2 / W_2$	L_2 =	________	ft
5-7. Verify that the length-to-width ratio of Cell 2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$	LW_2 =	________	
5-8. Enter percent of surface area that will be planted with emergent vegetation (25-75%), $\%A_{ev}$	$\%A_{ev}$ =	________	%
5-9. Calculate emergent vegetation surface area, $A_{ev} = (A_2 \bullet \%A_{ev})/100$	A_{ev} =	________	ft^2
5-10. Enter average depth of emergent vegetation shallow zone (1.5 - 3 ft), d_{ev}	d_{ev} =	________	ft
5-11. Calculate volume of emergent vegetation shallow zone (1.5 - 3 ft), $V_{ev} = A_{ev} \bullet d_{ev}$	V_{ev} =	________	ft^3
5-12. Enter width of emergent vegetation shallow zone, $W_{ev} = W_2$	W_{ev} =	________	ft
5-13. Calculate length of emergent vegetation shallow zone, $L_{ev} = A_{ev} / W_{ev}$	L_{ev} =	________	ft
5-14. Calculate volume in deep zone, $V_{deep} = V_2 - V_{ev}$	V_{deep} =	________	ft^3
5-15. Calculate surface area of deep (>3 ft) zone, $A_{deep} = A_2 - A_{ev}$	A_{deep} =	________	ft^2
5-16. Calculate the average depth in deep zone (4-8 ft), $d_{deep} = V_{deep} / A_{deep}$	d_{deep} =	________	ft
5-17. Enter width of deep zone, $W_{deep} = W_2$	W_{deep} =	________	ft
5-18. Calculate length of deep zone, $L_{deep} = A_{deep} / W_{deep}$	L_{deep} =	________	ft
Step 6: Ensure Design Requirements and Site Constraints are Achieved			
6-1. Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the pond is inadequate to meet the design requirements, choose a new location for the pond.			
Step 7: Size Outlet Structure			
7-1. Please refer to Appendix D for pond outlet structure sizing methodologies and examples. The pond outlet pipe shall be sized, at a minimum, to pass flows greater than the water quality design peak flow for off-line basins or flow from the capital storm for on-line basins.			

Step 8: Determine Emergency Spillway Requirements
8-1. For online basins, an emergency overflow spillway should be sized to pass the capital design storm to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Wet Retention Basin Design Example

Wet retention basin siting requires the following considerations prior to construction: (1) availability of base flow – wet retention basins require a regular source of water if water level is to be maintained, (2) surface space availability – large footprint area is required, and (3) compatibility with flood control – basins must not interfere with flood control functions of existing conveyance and detention structures.

The wet retention basin in this example does not have extended detention. An internal berm separates the forebay (Cell 1) and the main basin (Cell 2). The berm is at the elevation of the active volume design surface which is also the permanent wetpool elevation.

Step 1: Determine Water Quality Design Volume

For this design example, a 10-acre residential development with a 60% total impervious area is considered.

Step 1: Determine storm water quality design volume, V_{wq}			
1-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} =	25,700	ft^3

Step 2: Determine Active Design Volume for a Wet Retention Basin without Extended Detention

If there is no extended detention provided, wet retention basins shall be sized to provide a minimum wet pool volume equal to the water quality design volume plus an additional 5% for sediment accumulation.

Step 2: Determine Active Design Volume for the Wet Pond without Extended Detention			
2-1. Calculate the active design volume (without extended detention), $V_a = 1.05V_{wq}$	V_a =	26,985	ft^3

Step 3: Determine Retention Basin Location and Preliminary Geometry Based on Site Constraints

A total footprint area and total length available for the basin is provided. This step calculates the total active volume surface area which is equivalent to the permanent wetpool surface area. This step also calculates the dimensions of the internal berm.

Step 3: Determine Pond Location and Preliminary Geometry Based on Site Constraints			
3-1. Based on site constraints, determine the pond geometry and the storage available by developing an elevation-storage relationship for the pond. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2.			
3-2. Enter the total surface area of the pond footprint based on site constraints, A_{tot}	A_{tot} =	11,000	ft^2
3-3. Enter the length of the pond footprint based on site constraints, L_{tot}	L_{tot} =	200	ft
3-4. Calculate the width of the pond footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} =	55	ft
3-5. Enter interior side slope as length per unit height (min = 3), Z	Z =	3	
3-6. Enter desired freeboard depth, d_{fb}	d_{fb} =	2	ft
3-7. Calculate the length of the active volume surface area including the internal berm but excluding freeboard, $L_{av\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{av\text{-}tot}$ =	188	ft
3-8. Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{av\text{-}tot}$ =	43	ft
3-9. Calculate the total water quality surface area including the internal berm and excluding freeboard, $A_{av\text{-}tot} = L_{av\text{-}tot} \bullet W_{av\text{-}tot}$	$A_{av\text{-}tot}$ =	8,084	ft^2
3-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} =	6	ft
3-11. Enter the length of the internal berm, $L_{berm} = W_{av\text{-}tot}$	L_{berm} =	43	ft
3-12. Calculate the area of the berm, $A_{berm} = W_{berm} \bullet L_{berm}$	A_{berm} =	258	ft^2
3-13. Calculate the active volume surface area excluding the internal berm and freeboard, $A_{av} = A_{av\text{-}tot} - A_{berm}$	A_{av} =	7,826	ft^2

Step 4: Determine Dimensions of Cell 1

It should be assumed that Cell 1 (the forebay) should be 20% of the total active design volume, V_a.

Step 4: Determine Dimensions of Cell 1			
4-1. Enter the percent of V_a in Cell 1, $\%V_1$	$\%V_1$ =	20	%
4-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_a \cdot \%V_1)/100$	V_1 =	5,397	ft^3
4-3. Enter desired average depth of Cell 1 (5-9 ft including sediment storage of 1 ft), d_1	d_1 =	5	ft
4-4. Calculate the surface area for the active volume of Cell 1, $A_1 = V_1 / d_1$	A_1 =	1,079	ft^2
4-5. Enter the width of Cell 1, $W_1 = W_{av\text{-}tot} = L_{berm}$	W_1 =	43	ft
4-6. Calculate the length of Cell 1 (Note: inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W1$	L_1 =	25	ft

Step 5: Determine Dimensions of Cell 2

Verify that the surface area and length-to-width ratio of Cell 2 meet the design criteria. Calculate volumes, depths and surface areas for the emergent vegetation shallow zone and the deep zone.

Step 5: Determine Dimensions of Cell 2			
5-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$	V_2 =	21,588	ft^3
5-2. Determine minimum wetpool surface area, $A_{min2} = V_2 \cdot 0.3$	A_{min2} =	6,476	ft^2
5-3. Determine actual wetpool surface area, $A_2 = A_{av} - A_1$	A_2 =	6,747	ft^2
5-4. If A_2 is greater than A_{min2} then move on to step 5-5. If A_2 is less than A_{min2}, then modify input parameters to increase A_2 until it is greater than A_{min2}. If site constraints limit this criterion, then another site for the pond should be chosen.			
5-5. Enter width of Cell 2, $W_2 = W_1 = W_{av\text{-}tot} = L_{berm}$	W_2 =	43	ft
5-6. Calculate top length of Cell 2, $L_2 = A_2 / W_2$	L_2 =	157	ft
5-7. Verify that the length-to-width ratio of Cell 2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$	LW_2 =	4	
5-8. Enter percent of surface area that will be planted with emergent vegetation (25-75%), $\%A_{ev}$	$\%A_{ev}$ =	25	%
5-9. Calculate emergent vegetation surface area, $A_{ev} = (A_2 \cdot \%A_{ev})/100$	A_{ev} =	1,687	ft^2
5-10. Enter average depth of emergent vegetation shallow zone (1.5 - 3 ft), d_{ev}	d_{ev} =	2	ft
5-11. Calculate volume of emergent vegetation shallow zone (1.5 - 3 ft), $V_{ev} = A_{ev} \cdot d_{ev}$	V_{ev} =	3,373	ft^3

Step 5: Determine Dimensions of Cell 2			
5-12. Enter width of emergent vegetation shallow zone, $W_{ev} = W_2$	W_{ev} =	43	ft
5-13. Calculate length of emergent vegetation shallow zone, $L_{ev} = A_{ev} / W_{ev}$	L_{ev} =	39	ft
5-14. Calculate volume in deep zone, $V_{deep} = V_2 - V_{ev}$	V_{deep} =	18,215	ft^3
5-15. Calculate surface area of deep (>3 ft) zone, $A_{deep} = A_2 - A_{ev}$	A_{deep} =	5,060	ft^2
5-16. Calculate the average depth in deep zone (4-8 ft), $d_{deep} = V_{deep} / A_{deep}$	d_{deep} =	4	ft
5-17. Enter width of deep zone, $W_{deep} = W_2$	W_{deep} =	43	ft
5-18. Calculate length of deep zone, $L_{deep} = A_{deep} / W_{deep}$	L_{deep} =	118	ft

Step 6: Ensure Design Requirements and Site Conditions are Achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location for the basin.

Step 7: Size Outlet Structure

Please refer to Appendix F for basin outlet structure sizing methodologies and examples. The basin outlet pipe shall be sized, at a minimum, to pass flows greater than the water quality design peak flow for off-line basins or flow from the capital storm for on-line basins.

Step 8: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass the capital design storm to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Footnotes
Wetpool volumes less than or equal to 4,000 cubic feet (or 0.0918 acre-feet) may be single celled.

Dry Extended Detention Basin Worksheet

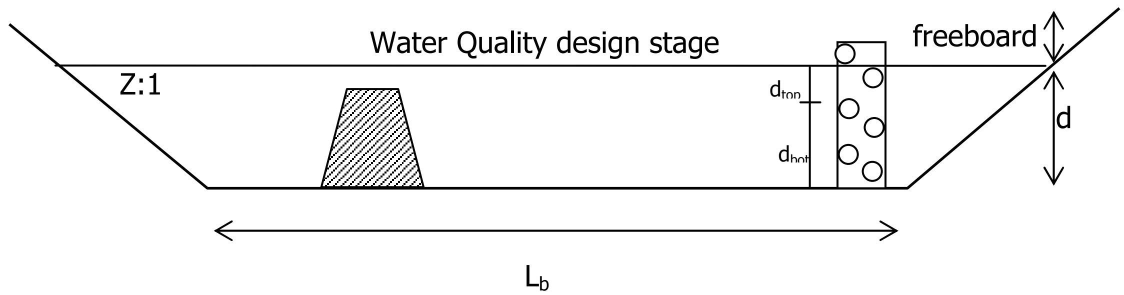

Figure D-9: Extended detention basin longitudinal profile

Refer to D-8 and Figure 6-28 for a diagrammatic description of the geometric variables.

Step 1: Determine design volume reduction, $V_{reduction}$	
1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25}, calculated using SBUH method, Appendix C	V_{25} = ____________ ft^3
1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one\text{-}inch}$, calculated using SBUH method, Appendix C	$V_{one\text{-}inch}$ = ____________ ft^3
1-3. Determine design volume reduction which is the larger of V_{25} and $V_{one\text{-}inch}$ and is the volume to be retained on-site	$V_{reduction}$ = ____________ ft^3
Step 2: Determine storm water quality design volume, V_{wq}	
2-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} = ____________ ft^3
Step 3: Determine design volume, V_{design} (for sizing)	
3-1. V_{design} = the larger of $V_{reduction}$ and V_{wq}	V_{design} = ____________ ft^3
Step 4: Calculate the volume of the active basin	
4-1. Calculate basin active volume, $V_a = 1.05V_{wq}$	V_a = ____________ ft^3

Step 5: Determine Detention Basin Location and Preliminary Geometry Based on Site Constraints		
5-1. Based on site constraints, determine the basin geometry and the storage available by developing an elevation-storage relationship for the basin. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2.		
5-2. Enter the total surface area of the basin footprint based on site constraints, A_{tot}	A_{tot} = ______	ft^2
5-3. Enter the length of the basin footprint based on site constraints, L_{tot}	L_{tot} = ______	ft
5-4. Calculate the width of the basin footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} = ______	ft
5-5. Enter interior side slope as length per unit height (min = 3), Z	Z = ______	
5-6. Enter desired freeboard depth, d_{fb}	d_{fb} = ______	ft
5-7. Calculate the length of the active volume surface area including the internal berm but excluding freeboard, $L_{av\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{av\text{-}tot}$ = ______	ft
5-8. Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{av\text{-}tot}$ = ______	ft
5-9. Calculate the total active volume surface area including the internal berm and excluding freeboard, $A_{av\text{-}tot} = L_{av\text{-}tot} \cdot W_{av\text{-}tot}$	$A_{av\text{-}tot}$ = ______	ft^2
5-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} = ______	ft
5-11. Enter the length of the internal berm, $L_{berm} = W_{av\text{-}tot}$	L_{berm} = ______	ft
5-12. Calculate the area of the berm, $A_{berm} = W_{berm} \cdot L_{berm}$	A_{berm} = ______	ft^2
5-13. Calculate the water quality surface area excluding the internal berm and freeboard, $A_{av} = A_{av\text{-}tot} - A_{berm}$	A_{av} = ______	ft^2
Step 6: Determine Dimensions of Cell 1		
6-1. Enter the percent of V_a in Cell 1 (25% required), $\%V_1$	$\%V_1$ = ______	%
6-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_a \cdot \%V_1)/100$	V_1 = ______	ft^3
6-3. Enter a desired average depth for the active volume of Cell 1, d_1	d_1 = ______	ft
6-4. Calculate the surface area for the active volume of Cell 1, $A_1 = V_1 / d_1$	A_1 = ______	ft^2
6-5. Enter the width of Cell 1, $W_1 = W_{av\text{-}tot} = L_{berm}$	W_1 = ______	ft
6-6. Calculate the length of Cell 1 (Note: inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W_1$	L_1 = ______	ft

Step 7: Determine Dimensions of Cell 2		
7-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$	V_2 = ____________	ft^3
7-2. Calculate the surface area of the active volume of Cell 2, $A_2 = A_{av} - A_1$	A_2 = ____________	ft^2
7-3. Calculate the average depth of the active volume of Cell 2, $d_2 = V_2 / A_2$	d_2 = ____________	ft
7-4. Enter the width of Cell 2, $W_2 = W_1 = W_{av\text{-}tot} = L_{berm}$	W_2 = ____________	ft
7-5. Calculate the length of Cell 2, $L_2 = A_2 / W_2$	L_2 = ____________	ft
7-6. Calculate the width of Cell 2 at half of d_2, $W_{mid2} = W_2 - Zd_2$	W_{mid2} = ____________	ft
7-7. Calculate the length of Cell 2 at half of $d_{2,}$ $L_{mid2} = W_2 - Zd_2$	L_{mid2} = ____________	ft
7-8. Verify that the length-to-width ratio of Cell 2 at half of d_2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the basin should be chosen, $LW_{mid2} = L_{mid2} / W_{mid2}$	LW_{mid2} = ____________	
Step 8: Ensure Design Requirements and Site Constraints are Achieved		
8-1. Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location.		
Step 9: Size Outlet Structure		
9-1. Refer to Appendix F for basin outlet structure sizing methodologies and examples. The total drawdown time for the basin should be 48 hours. The outlet structure shall be designed to release the bottom 50% of the detention volume (half-full to empty) over 32 hours, and the top half (full to half-full) in 16 hours. A primary overflow should be sized to pass the peak flow rate from the developed capital design storm.		
Step 10: Determine Emergency Spillway Requirements		
10-1. For online basins, an emergency overflow spillway should be sized to pass the capital design storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.		

Dry Extended Detention Basin Design Example

Step 1: Determine Storm Water Quality Design Volume Reduction, $V_{reduction}$

Step 1: Determine design volume reduction, $V_{reduction}$			
1-1. Enter the volume difference between the pre- and post-development conditions for the 25-yr, 24-hr design storm, V_{25}, calculated using SBUH method, Appendix C	V_{25} =	20	ft^3
1-2. Enter the volume generated from a one-inch, 24-hr storm event, $V_{one\text{-}inch}$, calculated using SBUH method, Appendix C	$V_{one\text{-}inch}$ =	25,700	ft^3
1-3. Determine design volume reduction which is the larger of V_{25} and $V_{one\text{-}inch}$ and is the volume to be retained on-site, if practical and feasible	$V_{reduction}$ =	25,700	ft^3

Step 2: Determine Storm Water Quality Design Volume, V_{wq}

Step 2: Determine storm water quality design volume, V_{wq}			
2-1. Determine the water quality design volume, V_{wq}, using SBUH method, Appendix C (Note: V_{wq} is always equal to $V_{one\text{-}inch}$)	V_{wq} =	25,700	ft^3

Step 3: Determine Design Volume, V_{design}

Step 3: Determine design volume, V_{design} (for sizing)			
3-1. V_{design} = the larger of $V_{reduction}$ and V_{wq}	V_{design} =	25,700	ft^3

Step 4: Calculate Volume of the Active Basin and the Forebay Basin

Step 4: Calculate the volume of the active basin			
4-1. Calculate basin active volume, $V_a = 1.05V_{wq}$	V_a =	26,985	ft^3

Step 5: Determine Detention Basin Location and Preliminary Geometry Based on Site Constraints

The detention basin in this example has an internal berm separating the forebay (Cell 1) and the main basin (Cell 2). The internal berm elevation is equivalent to the elevation of the active design volume. The berm length is equal to the width of the basin when filled to the active design volume.

Step 5: Determine Detention Basin Location and Preliminary Geometry Based on Site Constraints			
5-1. Based on site constraints, determine the basin geometry and the storage available by developing an elevation-storage relationship for the basin. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2.			
5-2. Enter the total surface area of the basin footprint based on site constraints, A_{tot}	A_{tot} =	11,000	ft^2
5-3. Enter the length of the basin footprint based on site constraints, L_{tot}	L_{tot} =	200	ft
5-4. Calculate the width of the basin footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} =	55	ft
5-5. Enter interior side slope as length per unit height (min = 3), Z	Z =	3	
5-6. Enter desired freeboard depth, d_{fb}	d_{fb} =	2	ft
5-7. Calculate the length of the active volume surface area including the internal berm but excluding freeboard, $L_{av\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{av\text{-}tot}$ =	188	ft
5-8. Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{av\text{-}tot}$ =	43	ft
5-9. Calculate the total active volume surface area including the internal berm and excluding freeboard, $A_{av\text{-}tot} = L_{av\text{-}tot} \cdot W_{av\text{-}tot}$	$A_{av\text{-}tot}$ =	8,084	ft^2
5-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} =	6	ft
5-11. Enter the length of the internal berm, $L_{berm} = W_{av\text{-}tot}$	L_{berm} =	43	ft
5-12. Calculate the area of the berm, $A_{berm} = W_{berm} \cdot L_{berm}$	A_{berm} =	258	ft^2
5-13. Calculate the water quality surface area excluding the internal berm and freeboard, $A_{av} = A_{av\text{-}tot} - A_{berm}$	A_{av} =	7,826	ft^2

Step 6: Calculate Dimensions of Cell 1

Calculate the dimensions of the forebay (Cell 1) based on the active design volume for Cell 1 (25% of V_a) and a desired average depth, d_1. The width of the forebay, W_1, is equivalent to the length of the berm, L_{berm}, and the width of Cell 2, W_2.

Step 6: Determine Dimensions of Cell 1			
6-1. Enter the percent of V_a in Cell 1 (25% required), $\%V_1$	$\%V_1$ =	25	%
6-2. Calculate the active volume of Cell 1 (including sediment storage), $V_1 = (V_a \cdot \%V_1)/100$	V_1 =	6,746	ft^3
6-3. Enter a desired average depth for the active volume of Cell 1, d_1	d_1 =	5	ft

Step 6: Determine Dimensions of Cell 1			
6-4. Calculate the surface area for the active volume of Cell 1, $A_1 = V_1 / d_1$	A_1 =	1,349	ft^2
6-5. Enter the width of Cell 1, $W_1 = W_{av\text{-}tot} = L_{berm}$	W_1 =	43	ft
6-6. Calculate the length of Cell 1 (<u>Note:</u> inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W_1$	L_1 =	31	ft

Step 7: Calculate the Dimensions of Cell 2

Calculate the dimensions of the main basin (Cell 2) based on the active design volume for Cell 2 and a desired average depth, d_2. A calculation of the length, L_{mid2}, and width, W_{mid2}, at half basin depth, d_2, is conducted in order to verify that the length-to-width ratio at half d_2 is greater than 1.5:1.

Step 7: Determine Dimensions of Cell 2			
7-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$	V_2 =	20,239	ft^3
7-2. Calculate the surface area of the active volume of Cell 2, $A_2 = A_{av} - A_1$	A_2 =	6,477	ft^2
7-3. Calculate the average depth of the active volume of Cell 2, $d_2 = V_2 / A_2$	d_2 =	3	ft
7-4. Enter the width of Cell 2, $W_2 = W_1 = W_{av\text{-}tot} = L_{berm}$	W_2 =	43	ft
7-5. Calculate the length of Cell 2, $L_2 = A_2 / W_2$	L_2 =	151	ft
7-6. Calculate the width of Cell 2 at half of d_2, $W_{mid2} = W_2 - Zd_2$	W_{mid2} =	34	ft
7-7. Calculate the length of Cell 2 at half of d_2, $L_{mid2} = W_2 - Zd_2$	L_{mid2} =	52	ft
7-8. Verify that the length-to-width ratio of Cell 2 at half of d_2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the basin should be chosen, $LW_{mid2} = L_{mid2} / W_{mid2}$	LW_{mid2} =	1.6	

Step 8: Ensure Design Requirements and Site Constraints are Achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location.

Step 9: Size Outlet Structure

Refer to Appendix F for basin outlet structure sizing methodologies and examples. The total drawdown time for the basin should be 48 hours. The outlet structure shall be designed to release the bottom 50% of the detention volume (half-full to empty) over 32 hours, and the top half (full to half-full) in 16 hours. A primary overflow should be sized to pass the peak flow rate from the developed capital design storm.

Step 10: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass the capital design storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.